

FY G345/0. 1977
no 68



Information Circular 68

1970

Chemical Analyses of Three Triassic(?) Diabase Dikes In Pennsylvania

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by Davis M. Lapham and Timothy E. Saylor

Staff Geologist

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Carddry & Carpenter, Inc.

PENNSYLVANIA GEOLOGICAL SURVEY
FOURTH SERIES
HARRISBURG

1970

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PREFACE

This report presents representative chemical analyses and mineralogical descriptions of samples for Triassic (?) diabase dikes in south-central Pennsylvania and one dike in northern Maryland. These data are directed toward the professional geologist interested in geographic distribution, overall uniformity, textural relationships, and mineralogy of igneous rocks as well as the relationship of these rocks to surrounding sedimentary rocks.

Chemical analyses are given in three tables in the text. The authors conclude from the analyses that the Gettysburg-Duncannon dike is quite uniform in character and that the Cornwall, Pennsylvania and Pilot, Maryland dikes exhibit features which are different from most diabases and tholeiites. The characteristics of the three dikes are analyzed and compared with the average tholeiitic dike and sheet composition.

This report presents the results of preliminary field work and petrologic interpretations which are part of a more comprehensive study of the composition and significance of Triassic diabase and magnetite ore deposition in Pennsylvania.

J. P. Wilshusen, Editor

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ABSTRACT

Major, minor and trace element analyses, together with cursory field and petrographic descriptions, are presented for 12 Triassic diabase samples from five locations between Gettysburg and Duncannon, one Triassic diabase dike sample from Cornwall in Lebanon County, and one Triassic(?) diabase dike sample from Pilot, Maryland. The Gettysburg-Duncannon dike is chemically quite uniform from its interior to its chilled margin and from north to south. Minor petrographic differences in grain size, texture, and mineralogy may or may not reflect a geographic distribution. The Cornwall and Pilot dikes are compositionally distinct. Al_2O_3 appears to vary inversely with TiO_2 . From data presently available, diabase dike and sheet compositions differ only slightly, but a wider distribution of analyses is required before definite conclusions can be reached.

INTRODUCTION

The Triassic(?) diabase dikes of the Appalachian region have been discussed briefly by King (1961) and Weigand (1970), and those of Pennsylvania by Nickelsen (1963) and Lapham (in Lapham and Gray, in press). In Pennsylvania, the dikes transect the structural grain of several geologic provinces: the crystalline rocks of the Piedmont lower-Paleozoic carbonates and clastics in the Piedmont, the sedimentary units of the Triassic basin, folded and thrust-faulted Great Valley carbonates, and the folded Valley and Ridge units of mid-Paleozoic age (Gray and others, 1960). Individual dikes show little or no trend deviation as they pass from one lithology to another, are steeply dipping and narrow (usually less than 100 feet wide), and may extend continuously for tens of miles (op. cit.). From Maryland into Pennsylvania to New Jersey, the strike of the dikes fans from NNW on the west to ENE on the east (Lapham in Lapham and Gray, in press). Contact metamorphism normally is slight. The diabase is a quartz-normative tholeiite (Weigand, 1970). The dikes are believed to be magmatically related to, and somewhat younger than, the more extensive Triassic sheets that are restricted to the northern portion of the Triassic basin where uppermost Triassic sedimentary rocks occur.

The data presented here are part of a more comprehensive study of the composition and geological significance of Triassic (or younger)

diabase (or dolerite) in Pennsylvania. These data are presented: 1) to augment our knowledge of the composition of Triassic tholeiitic basalt magma, 2) to help determine the extent, if any, of magma fractionation with respect to the probably earlier sheet intrusions, 3) as part of a study of the relationship between diabase composition and magnetite ore concentrations, and 4) to seek data that may bear upon the mode of dike intrusion. This report is a preliminary step toward these objectives and contains only cursory field and petrographic descriptions as an adjunct to major, minor, and trace element analyses.



Figure 1. Location of Chemically Analyzed Diabase Samples

Data for dikes from three areas are presented (Figures 1 and 2): 1) a nearly continuous, 50-mile long dike from Gettysburg on the south to Duncannon on the north (Figure 2), 2) a small dike from Cornwall, Lebanon County, and 3) a dike from Pilot, Maryland just south of the Pennsylvania state line. There is some uncertainty about the age of the latter diabase: it is slightly more altered than most Triassic(?) dike samples but considerably less altered than many known Ordovician (or older) diabases.

This work was sponsored by the Pennsylvania Geological Survey under the direction of Arthur Socolow, State Geologist. Field work was performed by T. E. Saylor (Gettysburg-Duncannon dike), Carlyle Gray (Cornwall dike), and D. M. Lapham (Pilot, Maryland dike). Cursory petrographic data from 44 thin sections were obtained by D. M. Lapham. D. B. MacLachlan, Pennsylvania Geological Survey, provided field data on the Gettysburg-Duncannon dike west of New Kensington and Robert Smith and Arthur Rose, Pennsylvania State University, kindly provided critical comments on the Gettysburg-Duncannon dike from research in progress. Dana Kelley, Pennsylvania Geological Survey, reviewed the manuscript for publication.

SAMPLE LOCATION AND DESCRIPTION

THE GETTYSBURG-DUNCANNON DIKE

General Statement

The diabase dike, sampled at five locations from Gettysburg to Duncannon (Figure 2) is part of a nearly continuous dike extending for more than 50 miles. This dike is near the western limit of dike occurrences in Pennsylvania, is generally less than 100 feet wide, and is vertical to steeply southeast dipping. The overall trend of the dike is about $N10^{\circ}E$, but segments range from $N20^{\circ}W$ to $N50^{\circ}E$ with systematic strike maxima that may form an extension and shear set at 30° to each other (Figure 2). Country rock at the contacts is slightly hornfelsed, may be slightly bleached with the reduction of hematite to dust-sized particles of magnetite, is somewhat recrystallized where the host is a carbonate, and occasionally is sheared. In general, contact effects are slight and introduced minerals are insignificant or absent at the localities sampled. Neither diabase pegmatite nor granophyre has been observed.

The samples are described and presented in Tables 1 and 2 from north (location 1, Figure 2) to south (location 5, Figure 2).

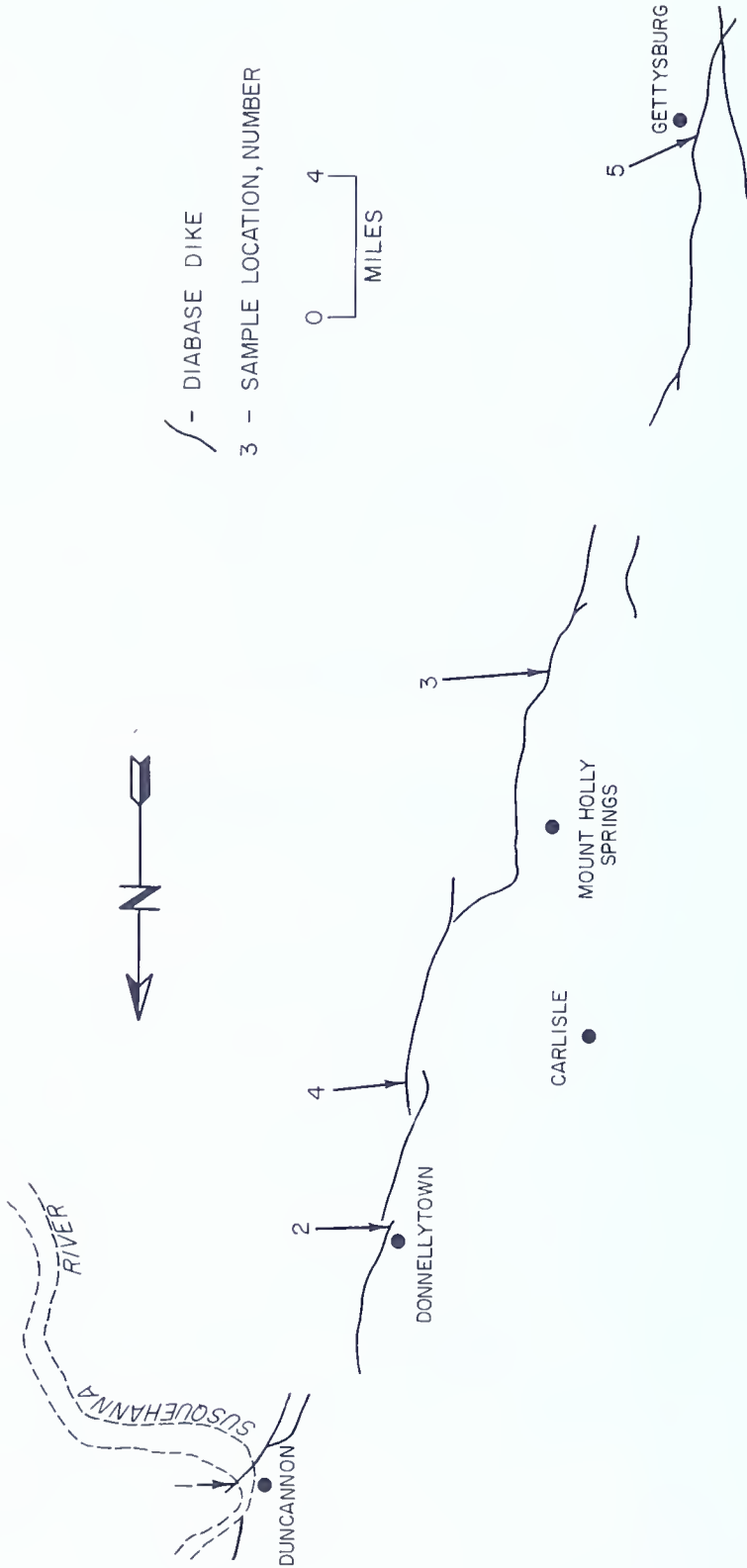


Figure 2. Location of Chemically Analyzed Samples of the Gettysburg-Duncannon Diabase Dike

Duncannon Samples (Location 1)

Samples were collected from outcrop along U.S. Route 22-North in a Pennsylvania Railroad cut on the east shore of the Susquehanna River about one mile east of Duncannon (Figure 2).

At this location, the dike strikes N40°E. and dips about 85°SE. The total width of the dike is about 45 feet and the chilled margin is about 6 inches thick. The dike intrudes the Catskill Formation, Duncannon Member, which is sheared at the contact. The diabase is well-fractured, deeply weathered, and generally fine-grained. Robert Smith (written communication) reports the presence of plagioclase phenocrysts here. Very small to dust-sized grains of magnetite are abundant in the country rock at the contact.

Sample 1-B1 was collected 1.5 feet from the west contact and is unweathered, fine-grained diabase, the grain length ranging from 0.08 to 0.5 mm. Texture is sub-ophitic. The major minerals are plagioclase and pyroxene, the amount of plagioclase being equal to, or slightly exceeding, that of pyroxene. Ca-poor pyroxenes (pigeonite > bronzite) and Ca-rich pyroxene occur without visible exsolution textures. Other minerals present include olivine (partially amphibolitized and < 2 percent), zoned plagioclase, and opaque oxides (2-3 percent). Micropegmatite is absent. Alteration consists of slight amphibolitization, sericitization, and serpentinization.

Sample 1-D was collected 23 feet from the west contact and is unweathered, medium to fine-grained diabase, the grain length ranging from 0.1 to 1.1 mm. Texture is ophitic to sub-ophitic. The major minerals are plagioclase and pyroxene, the amount of plagioclase being equal to, or slightly exceeding, that of pyroxene. Ca-poor pyroxene (orthopyroxene, pigeonite, inverted(?) pigeonite) rarely with very fine exsolution lamellae and Ca-rich pyroxene are present. Other minerals present include carbonate, biotite, needles of a green amphibole(?), rarely quartz, and opaque oxides (1-2 percent). Micropegmatite is absent. Alteration consists of slight amphibolitization of pyroxene.

Donnellytown Samples (Location 2)

Samples were collected from outcrop three-fourths of a mile south of Donnellytown and three and a half miles east of Carlisle Springs along Conodoquinet Creek (Figure 2).

Here the diabase dike strikes N35°E and dips about 80°-90°SE. South of Donnellytown and west of New Kensington, drill core data indicate that the dike may dip west less than 80° (personal communication, D. B. MacLachlan). The total width of the dike is about 65 feet. The chilled margin contacts are obscured. The dike intrudes the lower Martinsburg Formation that contains considerable amounts of very fine-grained magnetite at the contact and is hornfelsed for about 15 feet on the west side. The Martinsburg contact on the east is obscured. The diabase is well-fractured (2-6 inch spacing), weathered, and generally fine grained.

Sample 2-B was collected about 4 feet from the west contact and is unweathered and fine-grained, grain length ranging from 0.05 to 0.4 mm. Texture is sub-ophitic. The minerals present include plagioclase (commonly untwinned or diffusely twinned), Ca-poor pyroxene (orthopyroxene and probably pigeonite), Ca-rich pyroxene, rather

fresh olivine (1-2 percent), and opaque oxides (about 3 percent). The amount of plagioclase exceeds that of pyroxene. Pyroxene exsolution and micropegmatite were not observed. Alteration consists of serpentinization of olivine and slight amphibolitization.

Sample 2-C was collected about 25 feet from the west contact and is unweathered and fine-grained, grain length ranging from 0.08 to 0.8 mm. Texture is sub-ophitic. The minerals present include plagioclase (with core-rim composition zones), Ca-poor pyroxene (pigeonite with less abundant orthopyroxene), Ca-rich pyroxene, opaque oxides (about 2 percent), and rarely quartz. The amount of plagioclase exceeds that of pyroxene. Alteration consists of slight amphibolitization of pyroxene. Micropegmatite is not present.

Carlisle Samples (Location 4)

Samples were collected from outcrop east of Carlisle along the Pennsylvania Turnpike, two miles north of Pennsylvania Route 641 (Figure 2).

Here the diabase dike strikes approximately N10°E and is nearly vertical. The total width of the dike is about 65 feet. At the east contact, the chilled margin is about two inches thick. It is less sharply defined on the west. The dike intrudes the St. Paul Group of carbonates and has recrystallized them only slightly. The diabase is uniformly fine grained to within one foot of the contact.

Sample 4-D was collected about 25 feet from the west contact and is unweathered and fine-grained, grain length ranging from 0.09 to 0.08 mm. Individual specimens have a phenocrystic texture (plagioclase) and contain blebs of quartz several millimeters in diameter. Texture is sub-ophitic. Minerals present include plagioclase (with optical-crystallographic scatter), Ca-poor pyroxene (orthopyroxene and pigeonite), Ca-rich pyroxene, relict cores of olivine (< 1 percent), opaque oxides (1-2 percent), and leucoxene. Pyroxene and plagioclase are present in about equal amounts. Some plagioclase is untwinned, or diffusely twinned, and contains needle inclusions (probably apatite). Alteration consists of serpentinization and/or amphibolitization of olivine and slight sericitization of plagioclase. Micropegmatite is absent.

Sample 4-E was collected 50 feet from the west contact and is unweathered and fine-grained, grain length ranging from about 0.08 to 0.6 mm. Texture is sub-ophitic. Minerals present include olivine (?) (grains completely altered to brown, nearly isotropic material), Ca-poor pyroxene (pigeonite > orthopyroxene), Ca-rich pyroxene, plagioclase (including zoned phenocrysts), and opaque oxides (about 2 percent). Pyroxene exsolution was not observed. Pyroxene and plagioclase are present in about equal amounts. Micropegmatite is absent.

Sample 4-F2 was collected at the east contact chilled margin, 65 feet from the west contact, and is unweathered and very fine-grained, grain length of phenocrysts ranging from 0.05 to 0.35 mm, in a finer-grained groundmass. Phenocryst minerals include serpentinized olivine (subhedral to euhedral), euhedral clinopyroxene, and euhedral plagioclase (at least as calcic as An₆₄). The amount of plagioclase phenocrysts greatly exceeds that of pyroxene. Olivine is least abundant. The groundmass exhibits considerable magnetite dust clouding. Serpentine veinlets transect the chilled margin. Alteration consists of serpentinization and possibly amphibolitization.

Mount Holly Springs Samples (Location 3)

Float samples were collected 4.5 miles ESE of Mount Holly Springs, about 1 mile west of Victory Church and west of Pennsylvania Route 94 (Figure 2).

Diabase here strikes NS and dips steeply, but exact attitudes could not be determined. Based on float distribution, the dike is approximately 100 feet thick; however, actual dike width probably is somewhat less. Some samples contain large (3-5 mm) phenocrysts of plagioclase. The groundmass ranges from fine-grained to moderately coarse-grained. The diabase is well-fractured and intrudes metarhyolite ("aporhyolite") of the South Mountain complex. Microshears in metarhyolite are common near diabase contacts.

Sample 3-B (float) was collected near the west contact and is slightly weathered and fine-grained, grain length ranging from 0.09 to 0.8 mm. Texture is ophitic to sub-ophitic. In hand specimen, mafic minerals appear to exceed felsic minerals, although in thin sections, the pyroxene/plagioclase ratio ranges from about 4/3 to 3/4. Minerals present include olivine (altered and < 1 percent), plagioclase (some bent crystals), Ca-poor pyroxene (orthopyroxene and (?) pigeonite), Ca-rich pyroxene apatite(?) in plagioclase, and opaque oxides (2-3 percent). No exsolution textures were observed in pyroxene. Micropegmatite is absent. Some amphibolitization (green) of pyroxene and sericitization of plagioclase (some intensely altered) occurred.

Sample 3-E1 (float) was collected about 25 feet from the west contact and is slightly weathered and medium to moderately coarse-grained, grain length ranging from 0.2 to 1.7 mm. Texture is ophitic to sub-ophitic with large crystals of pyroxene and plagioclase (> 1.0 mm). Minerals present include plagioclase, Ca-poor pyroxene, and opaque oxides (about 1 percent). The amount of pyroxene is equal to, or exceeds, that of plagioclase. Scarce, very fine, exsolution lamellae occur in Ca-poor pyroxene. A small amount of interstitial micropegmatite is present. Alteration is negligible.

Sample 3-F1 was collected near the east contact and is slightly weathered and fine-grained, grain length ranging from 0.08 to 0.5 mm. Texture is sub-ophitic with occasional large blebs of quartz several millimeters in diameter. Minerals present include plagioclase, Ca-poor pyroxene (orthopyroxene and pigeonite), possibly a Ca-rich pyroxene, unaltered and phenocrystic olivine (< 1 percent), and opaque oxides (about 2 percent). The amount of pyroxene is equal to, or exceeds, that of plagioclase. No pyroxene exsolution was observed. Micropegmatite is present (< 1 percent). Alteration is negligible.

Gettysburg Samples (Location 5)

Outcrop samples were collected northeast of U.S. Route 30 in an Eastern Maryland Railroad cut 1.5 miles northwest of Gettysburg (Figure 2).

The diabase dike here strikes N20°E and dips about 80°SE. The total width of the dike is approximately 45 feet and the chilled margin width does not exceed 4 inches. Grain size ranges from coarse grained (center) to aphanitic (margin). Some samples internal to the chilled margin contain zoned plagioclase phenocrysts. The diabase is well-fractured and intrudes Triassic Gettysburg Formation shale and siltstone. The sediments are hornfelsed for three feet from the contact and contain dust-sized magnetite that grades to hematite outward from the contact. Calcite veinlets also occur near the contact. Robert Smith (written communication) reports a small amount of malachite and cuprite(?) at the western contact.

Sample 5-C was collected about one foot from the west contact and is unweathered and fine-grained, grain length ranging from 0.09 to 0.6 mm. Texture is sub-ophitic. Minerals present include plagioclase (including diffusely twinned grains with strained extinction), Ca-poor pyroxene (pigeonite, inverted pigeonite, possibly a primary orthopyroxene), possibly a Ca-rich pyroxene, opaque oxides (2-3 percent), serpentine, biotite, leucoxene, and apatite (?) inclusions in plagioclase. Amount of pyroxene slightly exceeds that of plagioclase. Fine exsolution lamellae occur sparingly in Ca-poor pyroxene. Alteration is negligible and micropegmatite is absent.

Sample 5-H was collected about 28 feet from the west contact and is unweathered and coarse grained, grain length ranging from 0.2 to 2.0 mm. Texture is ophitic with rare myrmekite. Minerals present include plagioclase (multiply zoned crystals), Ca-poor pyroxene (orthopyroxene, pigeonite, inverted pigeonite), Ca-rich pyroxene (slightly purplish), opaque oxides (1 percent), quartz (interstitial), biotite, and leucoxene. Plagioclase amount exceeds that of pyroxene. Exsolution in Ca-poor pyroxene is common: coarse lamellae, fine lamellae, and coarse blebs. Herringbone twins are present. Micropegmatite is absent. There is no significant alteration, except for leucoxene.

Summary of Gettysburg-Duncannon Dike

The following generalizations appear to be valid based on the above descriptions and a brief examination of an additional 30 thin sections from the same five localities.

1. Grain size is generally fine (grain length from 0.1 to 1.0 mm) but some coarse-grained portions are present to the south (Mount Holly Springs and Gettysburg). Grain size is not solely related to dike width: a 45-foot wide dike at Gettysburg has the maximum grain size and a 65-foot wide dike at Carlisle is the finest grained.

2. Olivine is present at four out of the five localities and appears to be a universal trace constituent. Its occurrence is not restricted to the chilled margin.

3. Interstitial micropegmatite is only rarely present at one locality (Mount Holly Springs).

4. There is little or no oxidation of opaque oxides to leucoxene in contrast to its widespread occurrence in diabase sheets (Davidson and Wyllie, 1968; Lapham and Gray, in press).

5. Phenocrystic diabase is not restricted to the aphanitic chilled margin. Phenocrysts in fine-grained diabase occur at the Gettysburg, Mount Holly Springs, and Duncannon locations, although additional sampling is desirable to substantiate any geographic restriction.

6. Microscopically visible pyroxene exsolution is absent except in coarse-grained facies where grain length exceeds 0.8 mm. Twinned pyroxene is only slightly less restricted.

7. Zoned plagioclase is present, but not abundant, at every locality sampled. Zoning is particularly evident in phenocrysts.

8. Contact effects on the country rocks are minor: reduction of hematite to magnetite, calcite recrystallization, microshearing, and serpentinization.

THE CORNWALL DIKE

The Cornwall dike appears to transect banded ore in the open pit (western mine) of the Cornwall magnetite ore body. From field observation, it was presumed to be younger than both sheet diabase and ore. It is compositionally distinct from the Cornwall sheet diabase (Lapham, 1968; Lapham and Gray, in press). The dike is several feet thick, well-fractured, and aphanitic to very fine grained throughout. The dike samples collected are unweathered. No further field data are available (C. Gray, notebook on file, Pennsylvania Geological Survey) and the site is now inaccessible.

Mineral grain sizes in the dike sample studied (C2-1) range from a grain length of less than 0.01 mm to as large as 1.3 mm for altered phenocrysts. Texture is porphyritic with a very fine-grained, equigranular to acicular, altered ground mass. Most original minerals have been altered: to chlorite (from pyroxene) with minor serpentine (from olivine), clinozoisite (from plagioclase), and sericite (potassic feldspar). Relict orthopyroxene and plagioclase phenocrysts occur sparingly. Some altered, euhedral grains resemble orthoclase or nepheline in form. Leucoxene (about one per cent), opaques (about two per cent), actinolite, and isotropic material are optically identifiable. X-ray analysis indicates two compositional types of chlorite (both high-iron), potassic feldspar (probably largely ferriferous orthoclase; minor microcline), nepheline(?), calcic plagioclase, minor pyroxene (pigeonite $\pm$ augite), and minor amphibole (actinolite $\pm$ hornblende) listed in order of decreasing abundance.

These data show that this dike is most probably pre-ore and has been subjected to the potassium metasomatism and ore-solution alteration accompanying magnetite introduction (see Lapham 1968; Lapham and Gray, in press). The form of the K_2O in this potassium-rich dike (Table 1) is largely introduced potassic feldspar; sericitization is minor.

THE PILOT, MARYLAND DIKE

A diabase dike has been mapped for a short length in the road triangle at Pilot, Maryland, about one mile south of the Pennsylvania state line and one-half mile east of the Susquehanna River. It occurs along, and parallel to, the north contact of a major serpentinite pluton (Lapham and McKague, 1964; Lapham, 1967) and, on the north, is in contact with pelitic schist (eastern Wissahickon facies) and/or boulder gneiss (Southwick and Fisher, 1967). The dike strikes about $N30^\circ E$ and dips steeply southeast. Based on float, the dike thickness is between 20 and 75 feet and is medium grained throughout except for an aphanitic chilled

facies. The age of this dike is uncertain, but its relatively unaltered character suggests that it is Triassic.

A typical sample of this diabase is moderately to slightly weathered and contains grains ranging from 0.1 to 1.5 mm along with occasional plagioclase crystals up to 2.5 mm long. Textures are sub-ophitic and phenocrystic. Minerals present include olivine (now completely amphibolitized), plagioclase (commonly zoned, a composition range of $An_{32}-An_{64}$, unaltered), Ca-poor pyroxene (about 8 percent enstatite with schiller, scarce pigeonite), Ca-rich pyroxene (uncommon), opaque minerals (magnetite, hematite), rarely quartz, green amphibole (< 3 percent), serpentine (< 2 percent), sericite, and biotite. The pyroxene/plagioclase ratio is $1/3$. There is no microscopically visible pyroxene exsolution. Micropegmatite is absent.

This sample differs slightly from the other Triassic (or younger) diabases described here. The pyroxene-to-plagioclase ratio is lower. Plagioclase crystals are noticeably embayed with broadly serrated prism edges. Alteration is somewhat more extensive, although considerably less than in nearby samples of Ordovician (or older) diabase and gabbro that are now amphibolites (Lapham unpublished data).

THE CHEMICAL ANALYSES

Major element, trace element, and comparative chemical analyses for the diabase dikes described here are presented in Tables 1, 2, and 3, respectively. Commercial analyses of diabase are compared with a commercial analysis of the BCR-1 standard for major and trace elements in Tables 1 and 2 respectively. The BCR-1 major element analysis falls within the accepted standard range for all elements. The BCR-1 trace element analysis is generally within acceptable limits except for nickel and zinc (Table 2), for both of which the commercial BCR-1 analysis is lower than the reported amount (Carmichael and others, 1968). Thus, the diabase analyses of nickel and zinc also are believed to be too low.

Two diabase samples that had been analyzed commercially (1-D and 2-H, Table 2) were analyzed at Pennsylvania State University along with a W-1 standard as an unknown (a good agreement with the standard was obtained, written communication, Robert Smith) to obtain a trace element comparison among laboratories. With the exceptions of barium and strontium, the agreement between the two laboratories is very poor (Table 2). Based on expectable concentrations, the commercial analyses are believed to be less reliable, although at least niobium and zirconium are in the range reported by Gottfried and others (1968).

Table 1. Major Element Chemical Analyses of Triassic (?) Diabase Dikes (in %)

	1-B1*	1-D*	2-B*	2-C*	4-D*	4-E*	4-F2*	3-B*	3-E1*	3-F1*	5-C*	5-H*	C2-1**	99-17**	BCR-1*
SiO ₂	51.78	50.74	50.66	50.94	50.88	50.46	49.82	50.44	51.50	50.76	50.24	51.88	48.00	52.90	54.62
TiO ₂	0.73	0.71	0.71	0.73	0.73	0.73	0.75	0.75	0.71	0.73	0.73	0.73	0.90	0.97	2.25
Al ₂ O ₃	14.09	15.20	15.23	15.06	15.53	15.21	15.53	15.24	15.20	15.05	15.32	15.00	14.80	14.30	13.99
Fe ₂ O ₃	2.38	2.98	2.24	2.30	2.03	2.55	2.11	2.70	2.85	1.91	2.34	1.79	5.25	13.06 (Total Fe)	3.57
FeO	8.43	7.77	8.57	8.82	8.89	8.50	8.64	8.29	7.63	9.34	8.61	7.53	6.11		8.78
MnO	0.18	0.18	0.18	0.17	0.19	0.18	0.18	0.18	0.18	0.18	0.18	0.16	0.27	0.21	0.20
MgO	8.02	8.11	7.87	7.99	8.18	8.07	8.63	7.88	8.26	8.23	8.19	8.79	8.53	6.25	3.48
CaO	11.31	11.37	11.53	11.08	11.31	11.08	11.45	11.23	10.79	10.74	11.14	12.40	4.06	9.04	6.95
Na ₂ O	1.61	1.62	1.67	1.72	1.74	1.84	1.65	1.65	1.74	1.74	1.69	1.50	0.17	1.98	2.78
K ₂ O	0.30	0.32	0.30	0.30	0.34	0.34	1.38	0.40	0.35	0.29	0.39	0.34	6.70	1.20	1.45
H ₂ O-	0.25	0.30	0.10	0.14	0.08	0.11	0.24	0.10	0.15	0.19	0.10	0.18	4.05	1.53	1.22
H ₂ O+	1.15	1.06	1.22	1.16	1.20	1.25	1.08	1.30	1.09	1.21	1.14	1.02			0.54
P ₂ O ₅	0.11	0.11	0.11	0.11	0.11	0.12	0.11	0.11	0.12	0.11	0.12	0.11	N.A.	0.14	0.35
CO ₂	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	0.22	0.10	0.01
	100.34	100.47	100.39	100.52	101.21	100.44	101.57	100.27	100.57	100.48	100.19	101.43	99.06	101.68	100.19

* Analysis by E. L. Conwell and Co., Philadelphia, Pennsylvania checked and in agreement with BCR-1 standard ranges

** Analysis by Spectrochemical Laboratories, Inc., Pittsburgh, Pennsylvania

NA = No analysis determined

1-B1 and 1D: Dike at Duncannon; 1.5' and 23' respectively

2-B and 2-C: Dike at Donnellytown; 4' and 25' respectively

4-D, 4-E, and 4-F2: Dike at Carlisle; 25', 50', and 65' respectively

3-B, 3-E1, and 3-F1: Dike at Mount Holly Springs; 1' to 2', 25' and 65' respectively

5-C and 5-H: Dike at Gettysburg; 1' and 28' respectively

C2-1: Dike at Cornwall (Lapham and Gray, 1970)

99-17: Dike at Pilot, Maryland (probably Triassic)

BCR-1: Standard basalt, split 74, position 21

Table 2. Trace Element Chemical Analyses of Triassic(?) Diabase Dikes (in ppm)

	1-R1*	1-D*	1-D*	2-B*	2-C*	4-D*	4-E*	4-F2*	3-B*	3-E1*	3-F1*	5-C*	5-H*	5-H*	C2-1**	99-17**	BCR-1*	BCR-1 ¹²
B	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	<10	N.A.	N.A.
Ba	<100	<100	110	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	N.A.	10	650	760
Cl	13	40	N.A.	47	40	27	27	57	13	13	27	13	13	13	N.A.	N.A.	57	N.A.
Co	20	20	51	18	18	21	20	22	20	18	17	18	20	64	24	40	30	60
Cr	40	38	270	38	35	40	40	40	38	40	36	42	35	190	N.A.	116	18	11
Cu	15	15	45	15	20	14	14	15	15	15	15	14	15	51	N.A.	80	20	15
F (organic)	350	350	N.A.	350	300	300	300	300	350	350	300	350	350	N.A.	2300	N.A.	430	N.A.
Li	<50	<50	N.A.	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	N.A.	N.A.	15	N.A.
Mo	<10	<10	N.D.	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	N.D.	N.A.	<10	<10	N.A.
Ni	<20	<20	87	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	117	24	157	15	15
Nb	<20	<20	N.D.	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	N.D.	N.A.	N.A.	<20	N.A.
Pb	<30	<30	N.D.	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	N.D.	N.A.	<10	<30	5
S	800	680	N.A.	640	600	400	680	800	680	60	400	300	350	N.A.	600	910	410	N.A.
Sn	<20	<20	N.D.	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	N.D.	N.A.	<10	<20	N.A.
Sr	180	170	130	170	165	160	180	160	160	170	190	170	160	140	N.A.	N.A.	375	335
V	300-400	300-400	280	300-400	300-400	300-400	300-400	300-400	300-400	300-400	300-400	300-400	300-400	280	N.A.	56	400	323
Y	100-200	100-200	19	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	100-200	10	N.A.	N.A.	55	60
Yb	<10	<10	N.A.	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	N.A.	N.A.	N.A.	<10	N.A.
Zn	<10	<10	N.D.	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	N.D.	N.A.	24	<10	125
Zr	150-300	150-300	46	150-300	150-300	150-300	150-300	150-300	150-300	150-300	150-300	150-300	150-300	46	N.A.	N.A.	150	175

* For location and description of samples see text and Table 1

N.A. = No analysis determined

N.D. = Not detected

* Analysis by E. L. Conwell Co., Philadelphia, Pennsylvania

* Analysis by Norman Suhr, Mineral Constitution Laboratories, Pennsylvania State University

** Analysis by Spectrochemical Laboratories, Inc., Pittsburgh, Pennsylvania

BCR-1: Standard basalt, split 74, position 21; * Analysis by E. L. Conwell Co.; Analysis reported by Carmichael and others, 1968

Table 3. Comparative Chemical Analyses of Triassic(?) Diabase and Tholeiite (in %)

	1.	2.	3.	4.
SiO ₂	50.84	51.71	52.24	51.0
TiO ₂	0.73	0.93	1.13	1.4
Al ₂ O ₃	15.14	15.06	14.61	15.6
Fe ₂ O ₃	2.35	3.28	3.87	1.1
FeO	8.42	7.64	7.08	9.8
MnO	0.18	0.27	0.28	0.2
MgO	8.19	6.99	6.92	7.0
CaO	11.29	10.69	10.16	10.5
Na ₂ O	1.68	2.05	2.53	2.2
K ₂ O	0.42	0.67	0.75	1.0
H ₂ O total	1.32	1.10	0.94	—
Total Fe	8.06	8.12	8.22	8.38

1. Average of dike samples from Table 1, excluding C2-1 and 99-17
2. Average Triassic dikes of eastern North America excluding C2-1 and 99-17 (Table 1), (Lapham and Gray, in press)
3. Average Triassic sheets of eastern North America, excluding Cornwall, Pennsylvania (Lapham and Gray, in press)
4. Average tholeiite (Poldervaart, 1955)

From Table 1, it can be seen that the analyses for the Gettysburg-Duncannon dike are quite uniform and that there is no obvious change from north (location 1) to south (location 5). Samples from the chilled margin (4-F2 and 3-F1) and transitional chilled margin (1-B1 and 5-C) are not significantly different than samples from dike interiors. The coarse-grained diabase from Gettysburg (5-H) differs only very slightly from fine-grained diabase; somewhat more CaO, MgO and possibly SiO₂, and somewhat less FeO and Na₂O. In comparison with the analyses of Robert Smith (written communication, Pennsylvania State University) for this dike, these analyses are lower in K₂O and possibly Na₂O. Unpublished analyses for this dike by Peter Weigand (written communication) are lower in MgO and similarly higher in Na₂O.

The other two analyses (from Cornwall, Pennsylvania, and Pilot, Maryland Table 1)) differ noticeably. Compared with most diabases and tholeiites (Table 3), the Cornwall dike is anomalously high in Fe₂O₃, K₂O, and H₂O, and low in SiO₂, FeO, Na₂O, CaO. The Pilot, Maryland, dike is low in MgO and CaO, and high in alkalis. Both dikes occur in altered zones: the Cornwall in a potassium-metasomatized and hydrothermally altered magnetite ore zone, and the Pilot dike near steatitized and amphibolitized schist at a serpentinite contact. If the latter dike is of Triassic or younger age, the altered lower Paleozoic(?) metasediments could have influenced dike composition only by country-rock assimilation.

Based upon the currently available data, there is an inverse relationship between Al₂O₃ and TiO₂ contents in Pennsylvania Triassic(?) dia-

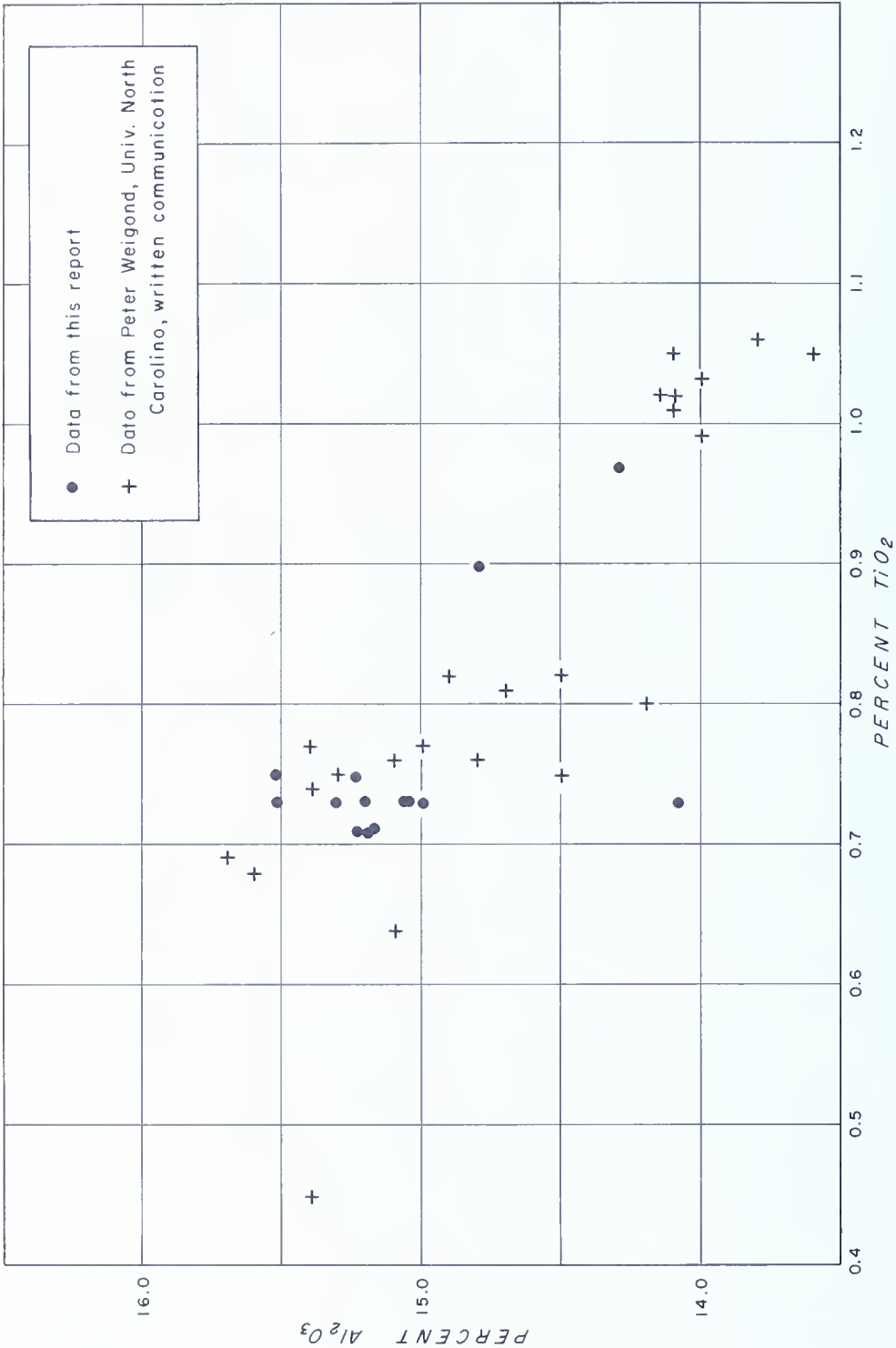


Figure 3. Percent Al_2O_3 versus TiO_2 in Pennsylvania Triassic (?) Diabase Dikes

base dikes (Figure 3). In part, it may be a function of differentiation since late ilmenite and magnetite content increase during differentiation as the more aluminum-rich calcic plagioclase content decreases (also see solidification index curves of Kuno, 1968). There also might have been differences in $\text{Al}_2\text{O}_3/\text{TiO}_2$ in the magma, either original or resulting from contamination, that influenced mixed spinel or silicate composition. However, as Davidson and Wyllie show (1968, Fig. 4, p. 954), mixed spinel is the only opaque component rich in aluminum, so that $\text{Al}_2\text{O}_3/\text{TiO}_2$ can change only if the ratio of mixed spinel to ilmenite changes. Increasing the amount of titaniferous augite (the most likely titanium-bearing silicate) may be rather ineffective because titanium-rich augites also tend to be more aluminous.

Of the trace elements, sulfur is the most variable (Table 2), indicating erratic distribution of sulfide minerals. Nickel is high in the Pilot dike (the serpentinite here contains as much as 0.58 percent NiO) and fluorine is high in the Cornwall dike. Trace element compositions for the Gettysburg-Duncannon dike are generally uniform regardless of geographic location, position within the dike, or grain size. In comparison with the data of Peter Weigand (written communication), these trace element data are lower in cobalt, chromium, copper, and nickel by factors of two to six and higher in strontium and zirconium by factors of one and a half to two.

In Table 3, an average composition for the Gettysburg-Duncannon dike is compared with averages for Triassic(?) dikes, sheets, and for tholeiite. H_2O^+ and H_2O^- have been combined for comparative purposes as total H_2O because many of the analyses used to compute the averages did not report both waters. Although all analyses in Table 3 are consistent with tholeiite compositions, some differences exist. In the Gettysburg-Duncannon dike, MgO and CaO are rather high whereas TiO_2 , Na_2O and K_2O are rather low.

Further sampling and analysis of these diabase dikes should be made to determine if the differences noted here are statistically valid and/or related to geographic distribution.

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